LOCAL ALIGNMENT OF THE TRANSMISSION LINE MAGNET

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Abstract

The transverse alignment strategy of the "Double-C" transmission line magnet over "short" distance scales (between the BPM's) is described.

1 INTRODUCTION

The alignment of transmission line magnets[1] for the VLHC/Injector[2] divides naturally into two distance scales. The *Global* alignment of the machines can be thought of as establishing the Beam Position Monitors (BPM's) at their nominal coordinates. The BPM's occur every ½ cell (~ 65m). The initial global alignment will be accomplished with normal survey techniques, and will eventually be replaced by beam-based alignment using the BPM's themselves during machine commissioning.

The subject of this note is the ***Local*** alignment of the transmission line magnet. Basically this means ensuring that the magnets are straight (or more precisely follow their nominal curvature) in the span between the BPM's. This is necessary to prevent loss of aperture due to 'kinks' in the magnets.

2 ALIGNMENT TOLERANCES

The R&D target for the straightness of the bore of the transmission line magnet, after alignment in the tunnel, is ±0.5 mm. This is also the alignment goal for the 50m prototype magnet. The meaning of this tolerance is that if the beam is centered perfectly at two successive BPM's, then the available radial aperture will be reduced by at most 0.5mm due to misalignments and kinks in the magnet.

Aperture requirements are discussed in Ref. 3. The nominal physical aperture of the magnets exceeds the beam envelope by 5mm. See Fig. 1. The 0.5mm local alignment tolerance means that 10% of the surplus aperture of the 3 TeV injector will be lost from magnet kinks.

The modulation of the beam envelope means that in principle the alignment tolerance could be loosened away from the β-max locations in each cell. Thus the 0.5mm tolerance only needs to be held in the horizontal (vertical) coordinate only within a 10-20m of the BPM at a horizontally (vertically) focussing location. The alignment tolerance could gradually loosen to as much as ±2 mm in the vicinity of the beam waists which occur at the defocusing BPM in each coordinate. See Fig. 1. However, if one allows the magnet to be out of alignment by this amount, then the effects on beam steering (closed orbit distortion) due to off-center propagation in the combined-function magnet will be significant[4]. Thus we do not plan to take advantage of this looser tolerance, and our goal is to hold the tighter 0.5mm tolerance throughout the length of the magnet.

We note that this extra radial aperture may prove useful by permitting beam orbit correction by deliberately decentering the gradient magnet the magnet in the vicinity of the beam waist. This allows correction of closed-orbit errors (via "quad steering" in the gradient magnets) without suffering loss of aperture.

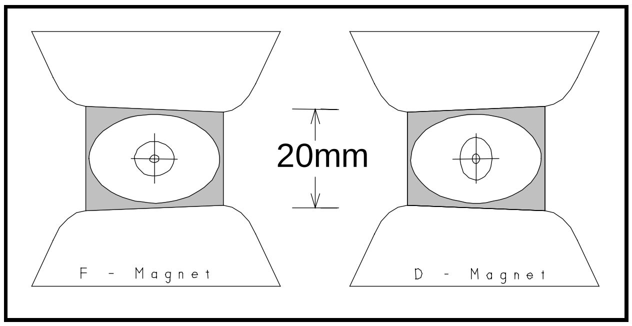

Fig. 1 - Beam Sizes in the 3 TeV Injector (from Ref. 3) -. The 95% beam envelopes for 15π beams (roughly the current FNAL collider emittances) are shown. The large ellipses show the beam envelope at injection energy (150 GeV). The small ellipses show the beam size at flattop (3000 GeV). Beam sizes in the 50 TeV machine are roughly 2x smaller. The left and right pictures indicate the beam envelopes in the in the vicinity of focussing and defocusing half-cell locations. Lattice functions are β min =130m, β max = 200m, Dx = 6m. Beam sizes - 150 GeV: Rmin=3.5mm, Rmax=4.3mm; 3000 GeV: Rmin=0.8mm, Rmax=1.0mm. The magnet gap is 20mm x 30mm (h x v) and the beam pipe aperture is 18mm x 27mm.

3 SURVEY

The first question is, "how do you know where the bore of the magnet is?" This is nontrivial issue for cold bore magnets. For the warm-iron design of the transmission line magnet, the position of the magnet gap at any point along its length can be known within 0.1mm from the position of survey notches on the magnet laminations. The position of the beam pipe extrusion, which will be clamped between the iron pole tips, will be known implicitly to the same precision.

The tunnel is very straight. Therefore there is always a line-of-sight between the BPM fiducials (or survey monuments) at adjacent half-cells. Thus the position of two BPM's and all of the intervening magnet laminations can be surveyed with a single optical setup. It should be possible to know the straightness of the magnet within ±0.25mm over the span between BPM's.

There may be issues in propagating a laser beam or line-of-sight straight to the required accuracy over the 65m half-cell. If necessary, the laser beam could be propagated in a vacuum pipe or helium bag.

4 DISTANCE SCALES

The straightness of the magnet must be addressed on several distance scales. See Figs. 2 and 3.

1) On a length scale <0.3m, the magnets are straight due to the rigidity of the laminated half-cores. The laminated cores are stacked on precise fixtures and contain longitudinal stiffening members (angle iron). A precisely machined aluminum spacer sets the magnet gap and ensures the relative alignment of the top and bottom half-cores.

2) On the length scale 0.3m-6m, the laminated cores are flexible and the magnet is aligned using welded connections to the structural tube that supports the magnet. The connections are made via skip welds every 30cm between the iron half-cores and the support beam (see Fig. 2). The half-cores are fixtured precisely in place as the welds are made, and the weld procedures will be designed to preserve that alignment. At the time that the welds are made, the support beam is in its relaxed state and is supported by alignment feet on the factory floor. The support beam is preloaded to pre-compensate for the sag (~2mm) of the magnet in the 6m between supports.

3) On distance scales 6m-75m, the structural tube is flexible and the magnet is aligned by adjusting the individual alignment feet. The process in 2) above guarantees a magnet that is straight when the magnet is supported with the feet in the nominal position on the factory floor. When the coordinates of the adjusters are reestablished in the tunnel, the magnet will again be straight.

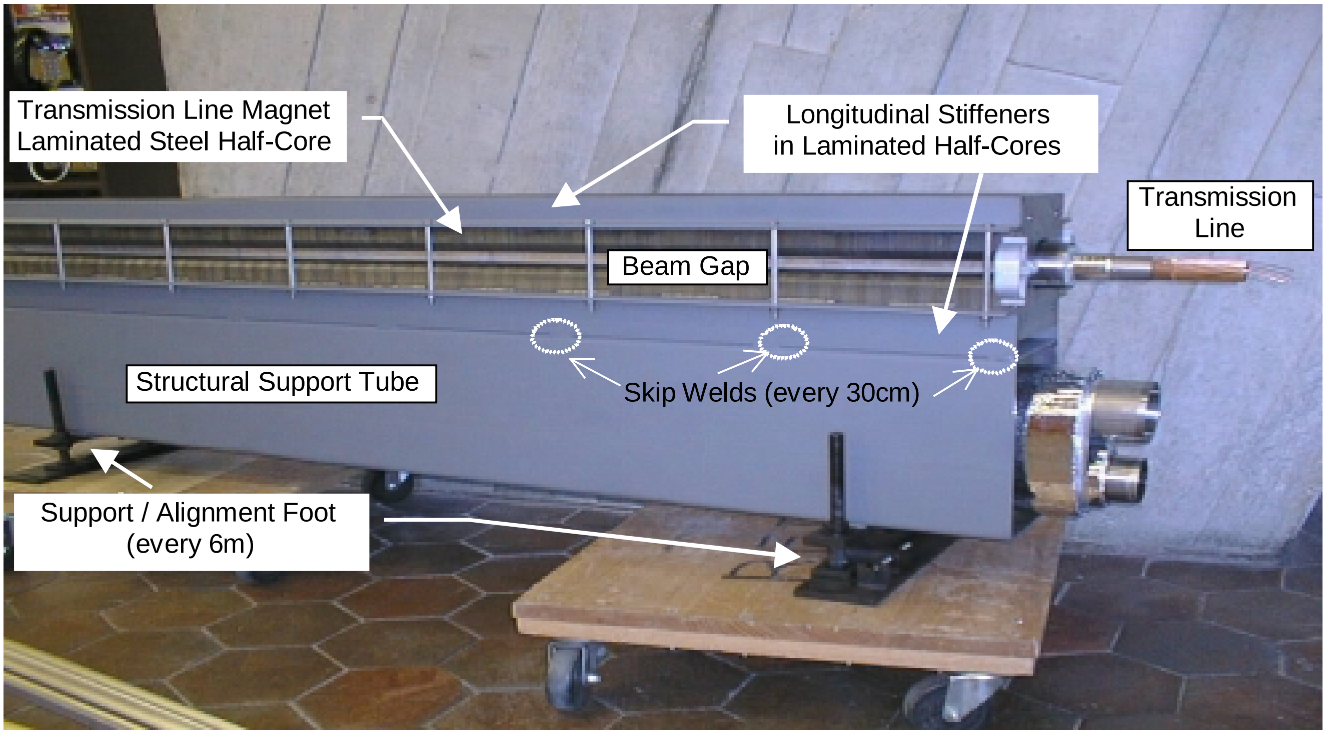

Fig. 2 – Components relevant to the alignment of the transmisssion line magnet.

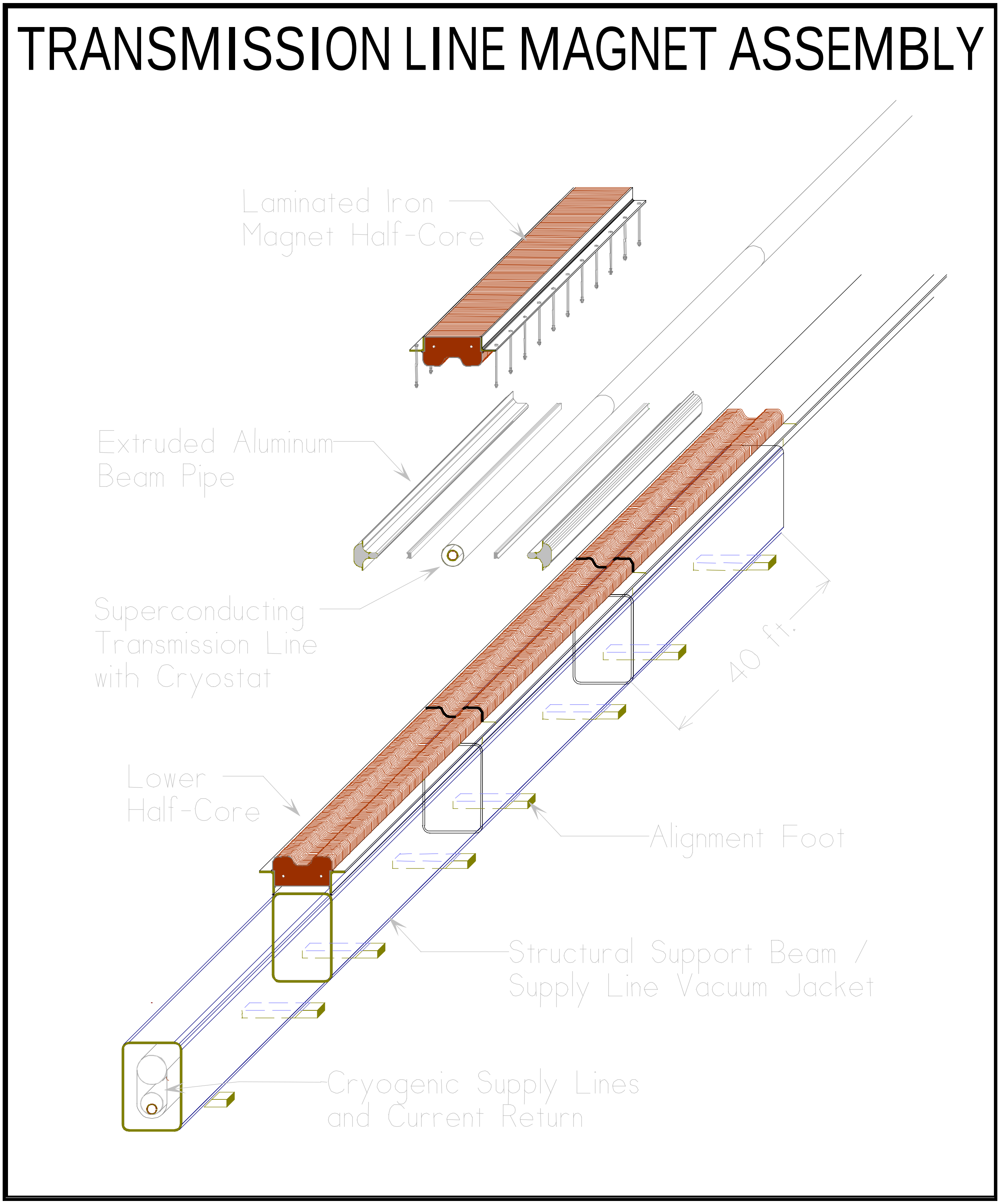

Fig. 3 - Assembly sequence for the transmission line magnet.

5 ALIGNMENT DECAY

Once established, the local alignment will decay over time due to motion of the tunnel floor. As before, the time dependent misalignment of the magnets can be decomposed into a component which is coherent over the half-cell (this drives closed-orbit distortions) and a part ("magnet kinks") which cause aperture reduction.

In bedrock tunnels such as the SPS [5] the RMS quad displacements grew at about 0.02mm per year horizontally and by 0.05mm/year vertically. One can (hopefully pessimistically) assume that all of this RMS is incoherent and will result in magnet kinks. Thus one can expect worst-case (5σ) kinks in the magnets which are equal to the initial $\pm$0.5mm assembly tolerance after about 2 years of operation. Whether or not this results in any aperture loss depends on where in the cell the kink occurs as discussed in section 2. In any case this sets the time scale for how often the magnets need be resurveyed (1-2 years) and how often one expects to remove a kink in a magnet anywhere in the ring to preserve the physical aperture (2-5 years). Magnet moves to preserve or correct the closed-orbit distortions will be more frequent occurrences.

6 AUTOMATION OF ALIGNMENT

In the 3 TeV injector there are 10 alignment fixtures in each half-cell, and a total of 5000 adjusters (15,000 alignment bolts) in the entire machine. Whenever a BPM is re-centered on the beam, in principle all 20 alignment fixtures on either side of the BPM should be realigned. This is a simple, repetitive procedure that cries out for an automated solution. This might take the form of an "alignment robot" which contains a conventional laser tracker and a motorized socket wrench for adjusting the magnet stands. Similar survey robots are already in use commercially for microtunneling of curved underground pipelines [6].

An advantage of this "robot" (actually a remotely operated servomechanism) is that beam-based alignment could take place by moving magnets in beam-on conditions. Survey and realignment and of the machine could take place on a continuing basis without need for dedicated downtime. The alignment robot might also find other uses, e.g. it could carry a PIN beam loss monitor to accurately localize beam losses.

7 STEPPING MOTORS

An alternative which is lower-tech but more flexible is to provide individual stepping motor controls on each magnet adjuster. If a cost of $200/motor ($600/adjuster) could be attained, the 5,000 adjusters for the 3 TeV machine would cost $3M. Considered as beam-steering correctors, these would have considerable excess strength and overlapping capabilities. Thus a sizeable fraction of the adjusters could be broken without affecting the ability to establish an acceptable closed orbit. The stepping motor approach does not eliminate the need for a survey robot since it is still necessary to know where to move the magnets.

REFERENCES

[1] "Status Report on the Transmission Line Magnet", G. W. Foster, contribution to the the FNAL 1997 VLHC summer study.

[2] "The Pipetron, a Low-Field Approach to a Very Large Hadron Collider' [The Pink Book], selected reports submitted to the Proceedings of the DPF/DPB Summer Study on New Directions in High-Energy Physics (Snowmass '96), compiled by Ernie Malamud (malamud@fnal.gov) Jan 1997. Current project information can be found at http:://www-AP.fnal.gov/ VLHC

[3] "Aperture Requirements for the Low Field VLHC and Injector", G. W. Foster, contribution to the FNAL 1997 VLHC summer study.

[4] "Pipetron Beam Dynamics with Noise", V. Shiltsev, contribution to the FNAL 1997 VLHC summer study.

[5] "Alignment Issues for the 3 TeV Ring", C.T. Murphy, contribution to the FNAL 1997 VLHC summer study.

[6] DYWIDAG (a large German tunneling concern) advertises robot theodelites for tunneling applications. Iseki Inc. in Japan uses remote-control survey devices with alignment lasers to microtunnel around corners.